LOOKING AHEAD – DAIRYING IN NEW YORK AND THE USA IN 2066

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Capacity of USA's agricultural land to feed the greatest population is fulfilled best by a diet that includes dairy products (Peters et al., 2016). Dairy provides required nutrients and dairy-based diets rank above vegan diets. This bodes well for the future of dairying. Mankind has been harvesting milk from cows for 200 centuries--that makes it less likely that dairying will not continue.

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OUR WORLD IN 2066

Population of the earth is forecast to be 10.4 billion in 2066 – about 3 billion greater than today (Figure 1). About 80% of the planet's inhabitants will live in Asia or Africa. Population of the USA will be 410 million, a lower global proportion than today. Worldwide, personal income will have increased and increased demand for high-quality dietary proteins will require increased output, efficiency and sustainability.

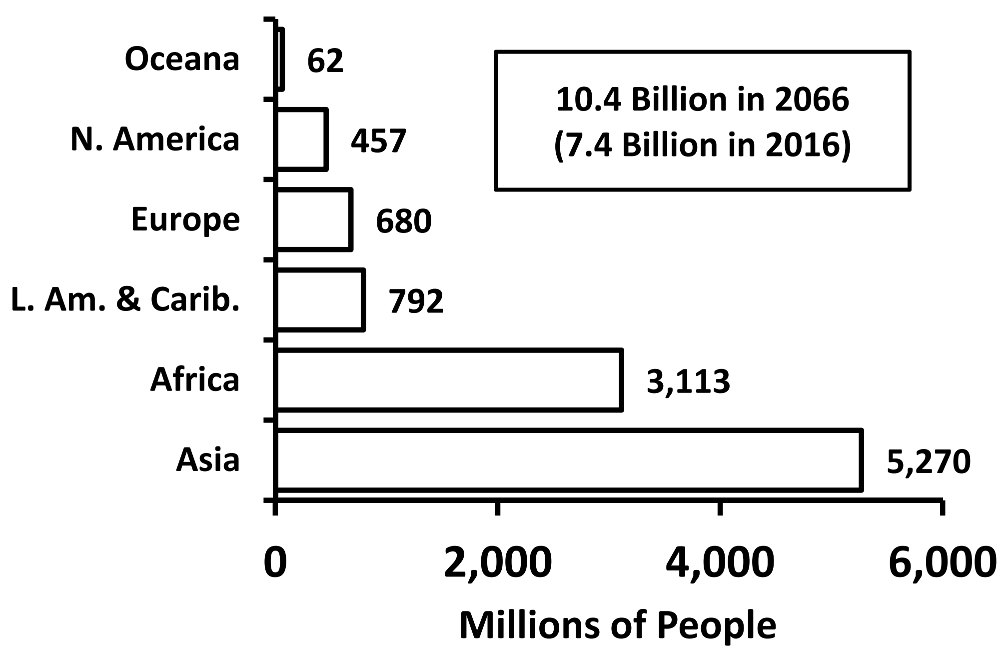

Figure 1. Estimated world population in 2066 (De Wulf, 2016).

CHANGING CLIMATE AND AGRICULTURE

Climate will change by 2066. This will drive shifts in where food is produced. Irrigation water will be rate-limiting, particularly for producing commodity crops, forages and grasslands. High-value crops will be produced with desalinated water. Crops will be genetically altered to use less water and water with higher salinity. Agriculture in the USA will remain highly-dependent on rainfall.

Currently 42% of milk in the USA is produced in states that will have shortages of water in 2066 (Figure 2). Dairy farming in the USA will relocate to regions with more water, particularly the upper Midwest and Great Lakes (Figure 2). In 2066, these regions will have growing seasons extended by 6 to 8 weeks in their most northern latitudes. Annual precipitation will be near current levels. A warmer climate, longer growing seasons and availability of water from precipitation makes these areas attractive for growth in dairy farming.

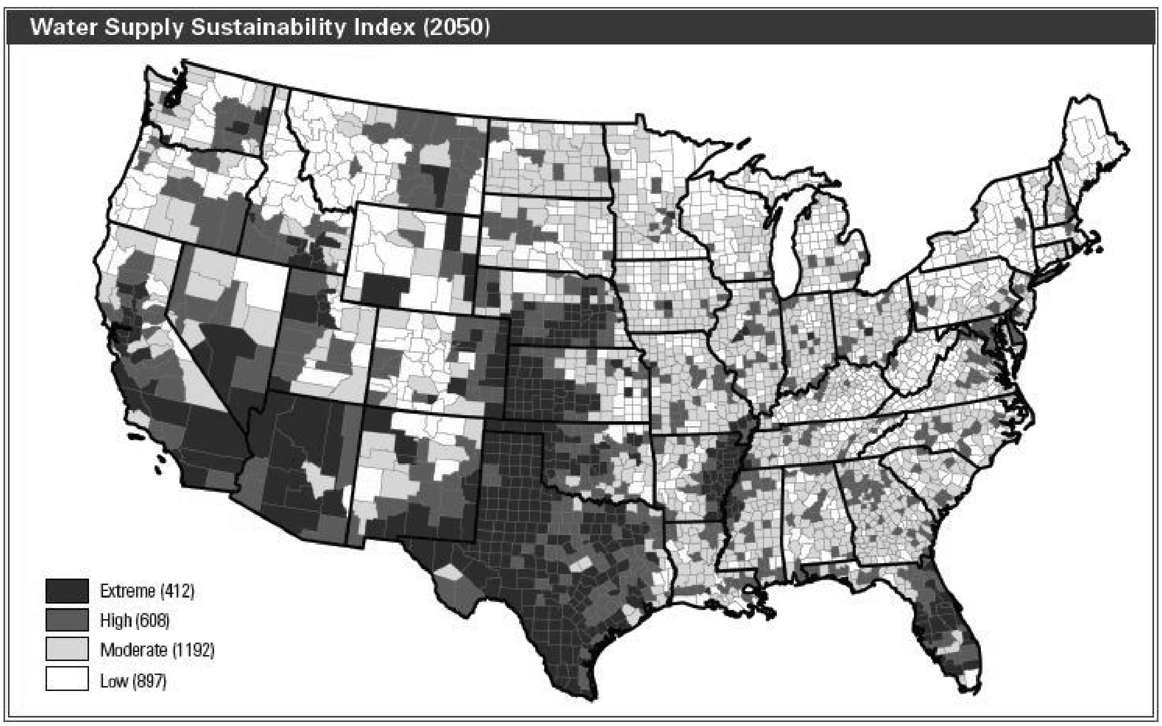

Figure 2. Forecast of water supply sustainability in 2050–darker areas less sustainable.

DAIRY CATTLE GENETICS AND MILK PRODUCTION IN 2066

Commercial dairy cattle in 2066 will comprise genes from multiple cattle breeds, but also from other species and even artificial genes (Figure 3). It is already possible through gene editing to change a single gene and therefore to “crossbreed” at the single gene level. In the future, genetic edits may be done in single embryos, essentially crossbreeding in the laboratory. Genetic companies of the future will market embryos as their primary product for commercial herds.

In 2066, farms will have on-farm systems that separate milk into components or classes, so milk will be sold on the basis of these characteristics. Quantity will still be important because total yield of components is correlated highly with total amount produced.

Annual yield will more than double in 2066 (Figure 4). Linear extrapolation reaches 36,000 lbs of milk per cow and exponential extrapolation reaches 72,000. Forecasters thought 57,500 lbs was on target. Individual cows in the USA first surpassed this level about 40 years ago, and recently a cow produced almost 75,000 lbs a year on 2X milking. The average cow in the USA today produces 2.65-times the amount that the average cow produced 50 years ago. If we multiply today's average by 2.65, it equals 59,341 lbs per year--forecasters feel comfortable with their estimate.

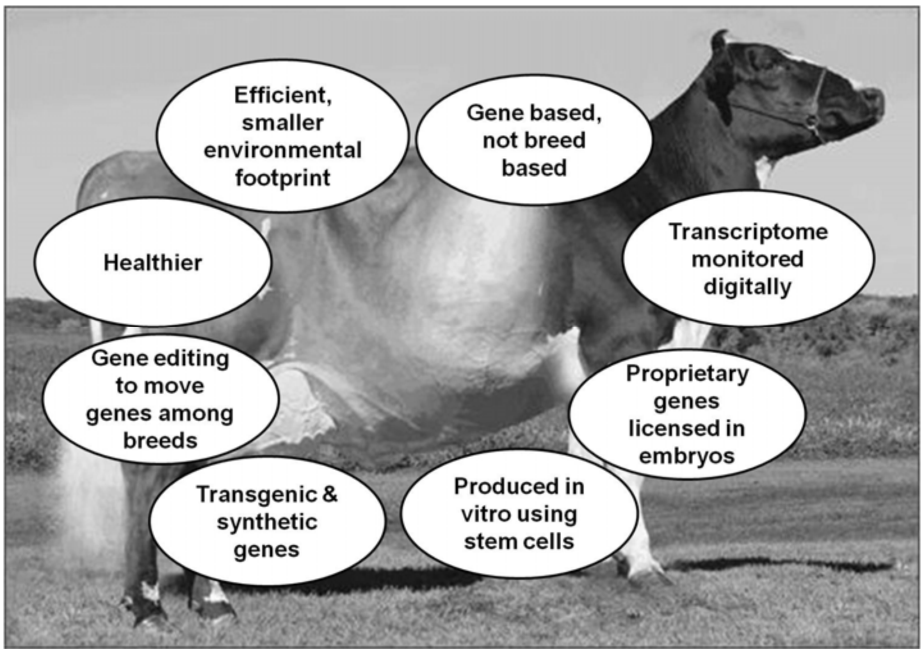

Figure 3. Examples of genetic changes in cows in 2066.

Are yields of milk and crops pushing their biological limits? The author assessed average and top yields in 2014 for three farm products (Table 1). Record yield was 7 to 12 standard deviation units (SDs) above average. Biological capacity to produce is far beyond average output in the USA.

Table 1. Record and average yields in USA.

	Corn (bu/acre)	Soybeans (bu/acre)	Milk (lbs/cow)
Record	504	161	74,650
Average	171	48	22,498
Std. Dev.	47.9	13.0	4,500
R-A(SDs)	7.0	8.7	11.6

Increase in yield per cow will drive down number of cows needed to meet the nation's demand for dairy products. The exact number will depend upon average yield and average consumption of fluid milk equivalents. The author assumed that consumption in fluid milk equivalents will be near today's level of 600 lbs per capita, which has been fairly constant over decades. If average yield reaches 57,500 lbs per cow, then we would need fewer than 5 million cows to supply this demand. These cows will be distributed in 500 to 600 herds nationwide.

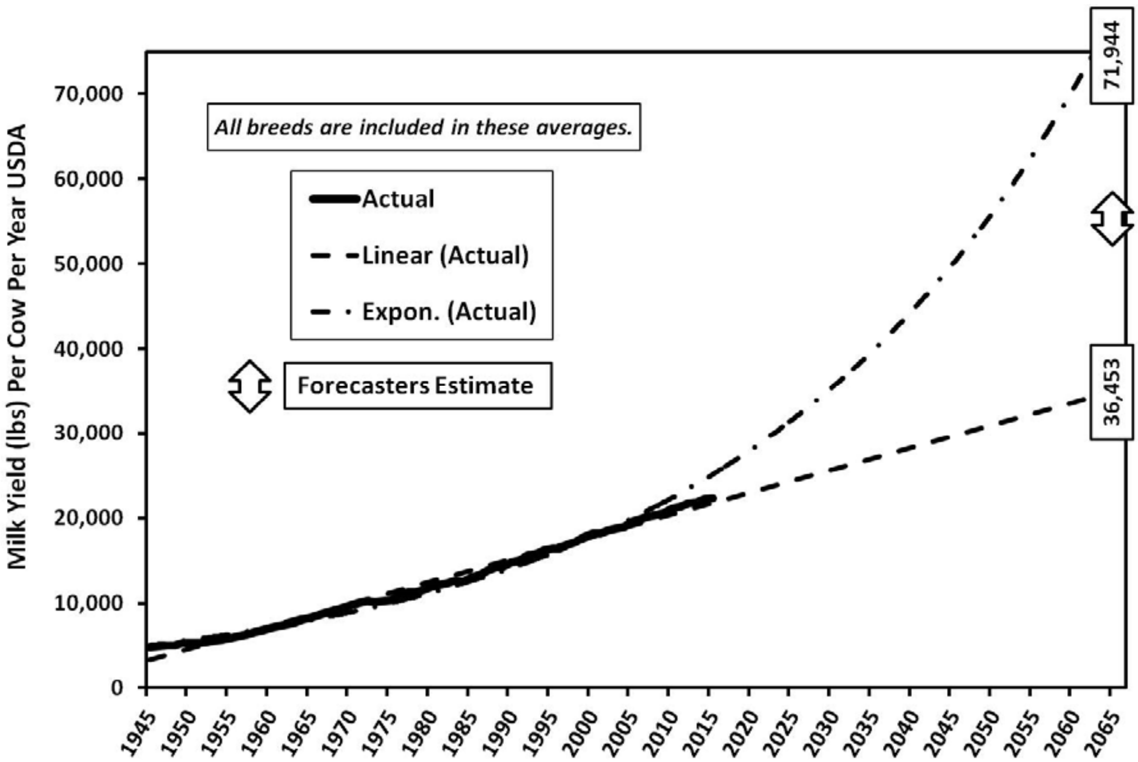

Figure 4. Estimated annual yield of milk in 2066.

DAIRY ENTERPRISES IN 2066

A dairy enterprise in 2066 will have about 10,000 cows in a cluster arrangement (Figure 5) that includes three milking herds supplied through shared heifer and dry cow units. A herd will comprise cows milked in the same parlor. Herds in the USA will be larger than those in Europe, but other countries may have herds of the sizes of the USA. Some general operating characteristics of herds are illustrated in Figure 5. Milk will be separated into market-based components at the farm level. Animal welfare plans will be required and will be inspected regularly. Forage crops will be more digestible and may include energy grasses that have been modified to be highly palatable and digestible.

Agro-ecology practices that ensure that herds operate sustainably within their ecosystems will be required. Nutrient management plans as we know them today may be relegated to history by 2066, because most valuable nutrients will be extracted from waste and used as fertilizer and marketed as co-products. Energy will be produced from fermentation of residual waste materials and downstream residuals will be used as soil amendments.

Concrete will not be a contact surface for cows' hooves in 2066, but it may provide a subsurface substrate. Carbon-based materials that have high strength along with cushioning properties will provide comfortable surfaces for cows.

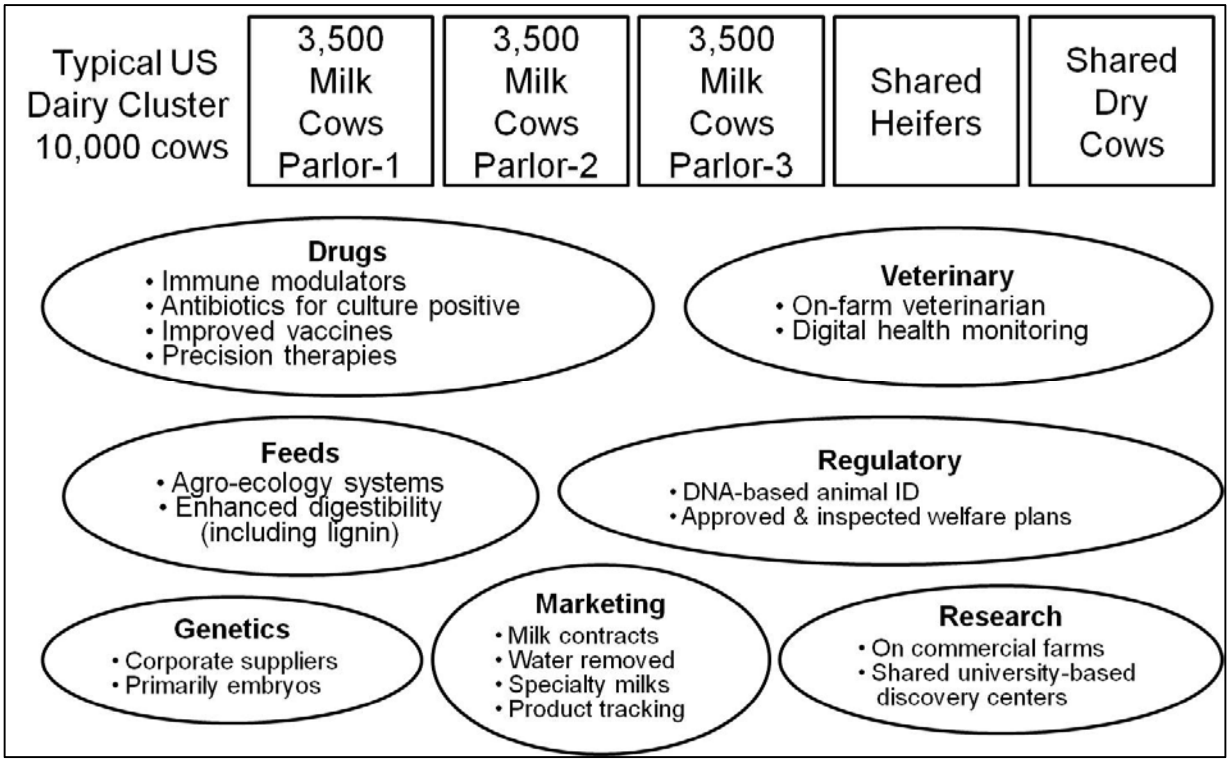

Figure 5. Characteristics of herds in 2066 including milking herd clusters and practices implemented on dairy farms.

DAIRY FARM TECHNOLOGIES IN 2066

Dairy farms in 2066 will be larger and feature robotics, sensors, automation, integrated systems, and natural-based methods for managing health, productivity and sustainability. Herds will be viewed as functioning like independent superorganisms.

Robotics, Sensors, Automation and Integrated Systems

Sensors will be employed across farmsteads to monitor soils, ground water and wells, waterways, roads, natural areas, waste storage systems, bedding and stalls, alleys, feed bunks, silos, commodity sheds, air, odors, particulates, pests, and safety (Figure 6). Some of these will provide data necessary for regulatory actions, but most will be part of enhanced focus on agro-ecology in farming operations worldwide.

Sensors will monitor activities of individual cows, including biodegradable sensors that will monitor gene transcription in the udder and liver. Health, activity and welfare will be monitored through sensors that measure immune status, infection or disease status, rumen function and several other biological traits. Data will be integrated and interpreted by the computer system and cows will have a “green, yellow or red” status for daily management.

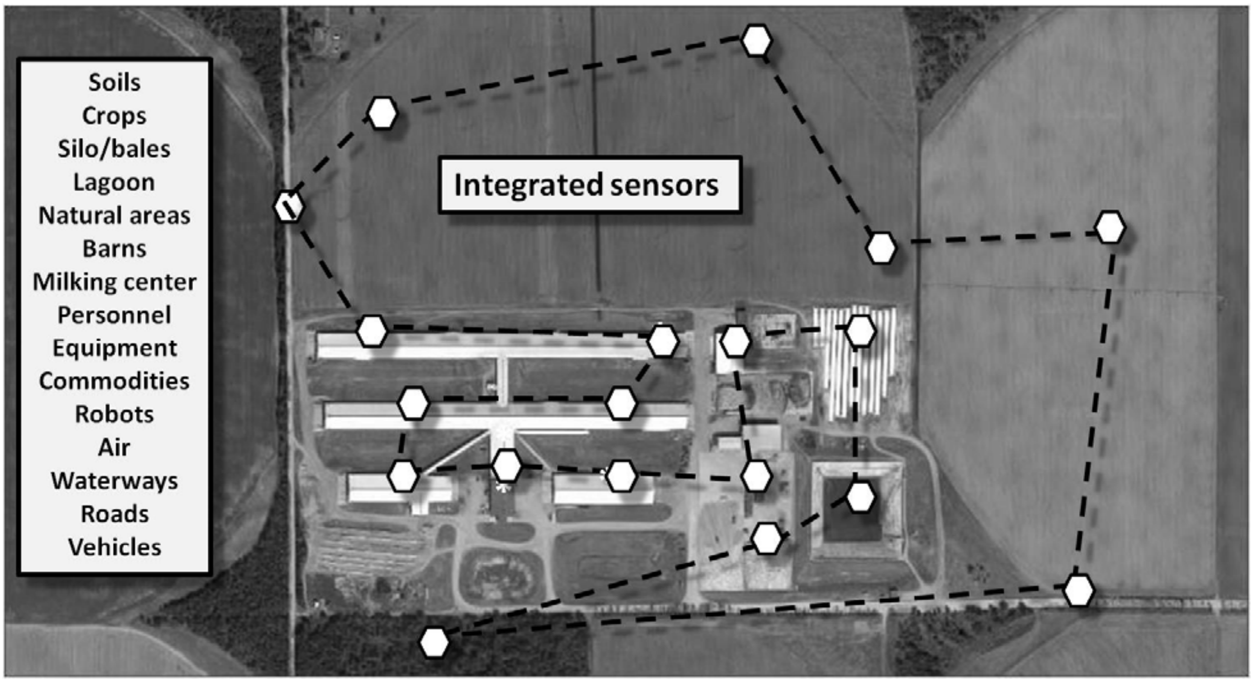

Figure 6. Sensors will be employed extensively on farms to monitor and manage resources and to comply with regulatory requirements.

Robotics and automation will largely replace manual labor on dairy farms and this will improve consistency in feeding, milking and animal health and welfare. Driverless equipment and robots will handle and mix feed, manage stalls and bedded areas, train heifers for entering the milking herd, clean alleys, aisles and milking areas, administer vaccinations, microbiomes, supplements and other products and complete other procedures that are part of the daily routine. In situations where manual labor is necessary, workers will be monitored electronically to ensure and improve compliance with standard operating procedures. Procedures will be improved consistently through feedback by the integrated data system.

Epigenetic Management

On average, about 20% of variation in dairy traits is attributable to DNA sequence or genome. Most variation is attributable to environmental effects according to the classical equation: Phenotype = Genetics + Environment. Environmental effects can be mediated through epigenetic processes in which the DNA sequence is not changed, but the expression of genes is altered. DNA bases can be methylated, histone proteins can be acetylated and small RNAs can be transcribed to control gene expression, all without a change in the DNA sequence. Manipulation or management of the epigenome in food animals will develop extensively over the next few decades (Sinclair et al., 2016)

The Britt Hypothesis (Britt, 1992; Carvalho et al, 2014) illustrates an example of an apparent detrimental epigenetic effect. In this case, significant negative energy balance during 3- to 5 weeks postpartum results in ovulation of defective oocytes 2-3 months later. Oocytes are affected initially within ovarian follicles during earliest stages of development and are ovulated about 100 days after the follicles are activated. After ovulation and fertilization, oocytes die at a rate much higher rate during 7 days after fertilization. This latent effect is an example of how epigenetics works.

Understanding of epigenetics is reaching a point where epigenetic management is beginning to be deployed in the dairy industry. For example, increasing milk intake and weight gain in heifers before weaning results in increased milk yields 2 years later. This type of delayed effect is classical for epigenetic processes and probably is mediated through an effect on mitotically-active cells like mammary epithelium.

By 2066, there will be many management procedures targeted toward manipulating the epigenome. These will include precisely-timed feeding, supplementing, regulating and controlling the ambient environment or specific processes to alter biological systems. These procedures will enhance reproduction, health, immune status, energetic efficiency, milk quality and yield and other important bioprocesses.

Managing the Microbiome

Animals, plants, soils, stored feeds, manure and the general environment of dairy farms comprise an “unseen” population of beneficial and symbiotic microorganisms (microbiome). Exploitation of this microbiome to enhance health and well-being of cattle, yield of crops, fertility of soils, quality of feeds and sustainability of environmental systems is emerging.

For several decades we have used antibiotics, insecticides, fungicides, sterilants, disinfectants and other anti-microbial materials to control infections, pests and crop diseases without giving appropriate attention to their effect on the beneficial microbiome. This will change quickly as we learn how to preserve and enhance the beneficial microbiome and apply it to benefit biological and environmental systems (Deusch et al., 2015). Examples of how managing the microbiome will be used in dairy herds in 2066 are illustrated in Table 2.

Table 2. Examples of microbiomic management that will be used in dairy farm production systems in 2066.

Agronomic	Environmental	Cow Specific	Therapeutic
Seeds Soils Crops Silages Forages Feeds	Drinking water Waste water Irrigation water Manure Bedding Facilities	Delivered by robotic systems	Sterile packs Intrauterine Intramammary Neonatal Some Rx

Microbiome profiles differ among herds and locations, so there will be no universal product that will work everywhere. Farms will purchase custom microbiome products from suppliers that will provide mixtures for their herd and location. Some products will be proprietary and will demand a premium price. Some products may require a prescription, depending on their activity and their classification by regulatory agencies, especially those that are genetically modified.

Farms will also manage their inherent microbiome profiles by altering practices that are detrimental to beneficial microorganisms. Microbiome scouts, much like crop scouts, will visit farms regularly to sample various microenvironments and provide advice and direction on the best microbiome products to utilize in that herd and location. Testing services will utilize bulk milk, feed, manure and waste water samples to monitor microbiome profiles of farms, much as feed testing is done today.

Feeding the Herd

Feed sources for dairy cattle will differ significantly by 2066. Research on recalcitrance of bioenergy crops will pay off for dairy farmers because high-yielding perennial crops with high levels of starch and high digestibility will displace corn as a feedstuff. In theory, perennial sugar cane has a capacity to yield about 90 tons of dry matter per acre per year with high starch levels (Moore 2009). Cold-tolerant lines of sugar cane are being developed and it will be grown at latitudes extending into the upper Midwest and Great Lakes regions as the climate warms. Other perennial forage grasses that need little nitrogen fertilizer to produce at high levels will also be arising from research that is ongoing today.

Herd as a Superorganism

The commercial dairy production unit is the herd, not the cow, and we have an inadequate understanding of how and why herds differ in health, productivity and sustainability. Generally it is said differences are due to management, but there is ambiguity about what that really means.

Scientists that study colonies of animals such as bees, termites and flocks of starlings refer to these groups as superorganisms. My interest in this was stimulated by reading *Honeybee Democracy* by Dr. Thomas Seeley, a Cornell neuroscientist (Seeley, 2010). Individual bees and terminates in hives or colonies are subservient to the reigning queen, so that makes them somewhat different than individual cows. Nevertheless, superoganisms comprise animals that live in the same environment, consume the same sources of food, are exposed to the same diseases and pests and may be under care of mankind. Does this sound familiar—same environment, same feed, same diseases and same management?

In contrast to those that study hives and colonies, most dairy scientists study individual animals or their systems (digestive, reproductive, mammary), organs, cells or genes. Little of the findings from such studies tell us much about what makes herds different. Should we devote more effort to understanding herds? If so, the herd becomes the experimental unit, not the individual cow. As we consider this, we might start by studying herds located within defined geographic areas that share similar weather, soils, types of crops and markets (Figure 7).

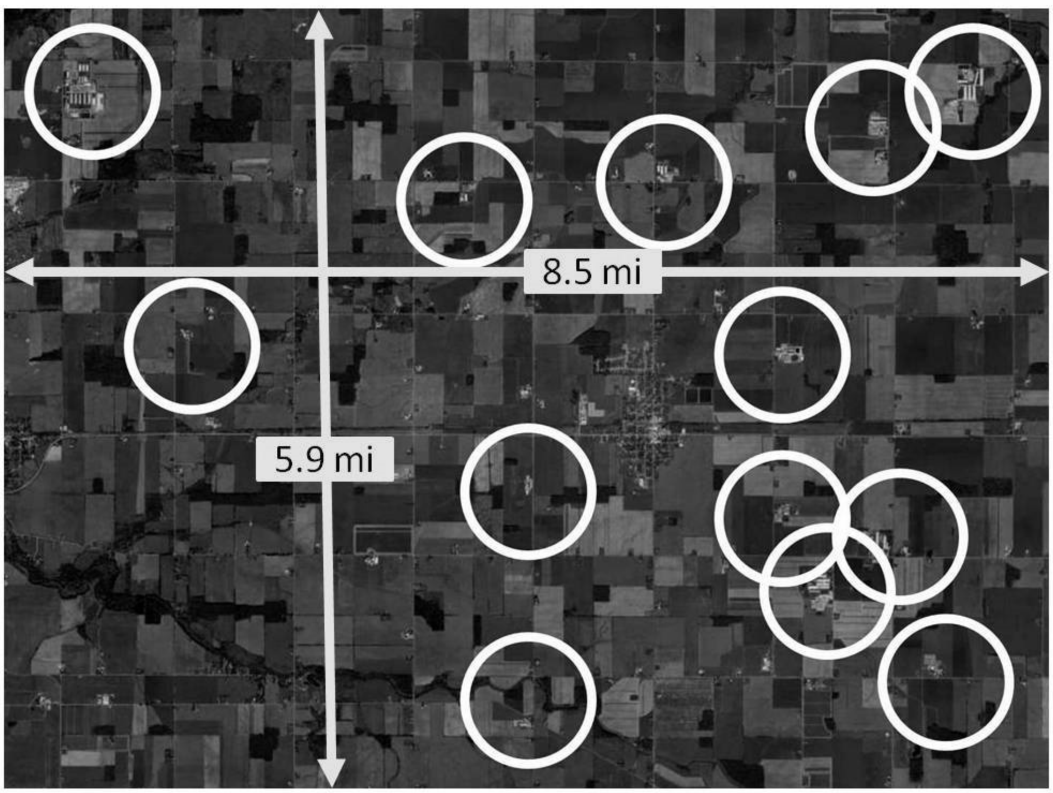

Figure 7. Example of 13 dairy herds in close proximity in a Midwestern area that shares common weather and growing seasons. Herds range from approximately100 to 1500 cows (created with Google maps).

How do goals of owners or managers differ? How do their practices differ? Where does feed quality rank among overall impact factors? Is biosecurity important? What role does compliance play? How do cows within these herds communicate with each other? The list of questions could be very long and there may be some important questions that are not asked because of our preordained opinions.

Why is it important to undertake this effort? By 2066 it will be imperative that food production be as efficient and sustainable as possible. We need answers to questions about productivity and sustainability of herds and the lands and waters that support herds in order to achieve these goals Furthermore, many of the findings would be useful in principal for dairy farmers worldwide, regardless of the sizes of their herds.

An undertaking to study herds should include university specialists, industry suppliers and customers, governmental agency representatives, farmers and farm organizations and consumers. It would be important to engage industrial engineers, data miners, systems specialists and other experts in such a study. Herd owners and managers that participate in such a study should receive periodic feedback that would be beneficial to them in the long run. There would not be typical “control” and “treatment” groups, so the types of statistical analyses might differ greatly from our traditional methodology. This is where outside experts would be extremely helpful.

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